ChatGPT

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A spin system is a physical system whose relevant degrees of freedom are **spins** rather than particle positions.

The simplest example is a collection of atoms fixed in a crystal lattice. The atoms do not move around much, but each atom carries a magnetic moment (often modeled as a spin) that can point up or down.

For example, consider N spins:

$$s_i = \pm 1.$$

The famous Ising model assigns an energy

$$E = -J \sum_{\langle i,j \rangle} s_i s_j.$$

The energy depends on the spin orientations, not on where the atoms are.

What makes spin systems special is that they often have a **bounded energy spectrum**. For instance, if each spin can only be up or down in a magnetic field,

$$E = -\mu B \sum_i s_i,$$

then the lowest-energy state is all spins aligned one way and the highest-energy state is all spins aligned the other way. There is a maximum possible energy.

Ordinary gases do not have this property. A gas molecule can always move faster, so the energy has no upper bound.

This bounded spectrum allows peculiar states. Temperature is defined through

$$\frac{1}{T} = \frac{\partial S}{\partial E}.$$

Normally, increasing energy increases entropy, so $\partial S/\partial E > 0$ and $T > 0$.

In a spin system, once most spins occupy the high-energy states, adding more energy can actually *decrease* the number of accessible configurations. Then

$$\frac{\partial S}{\partial E} < 0,$$

which corresponds to a **negative absolute temperature**.

A classic realization is a collection of nuclear spins in a crystal placed in a magnetic field. By using radio-frequency pulses, experimenters can invert the population so that more spins occupy high-energy states than low-energy states. Such states have been produced experimentally.

Negative-temperature states are not colder than absolute zero. In fact, they are formally *hotter than any positive temperature*, because if brought into contact with an ordinary system, energy flows from the negative-temperature system into the positive-temperature one.

The mention of negative pressure arises because thermodynamic identities connect pressure, entropy, volume, and energy. Some bounded-spectrum systems can enter regimes where the thermodynamic pressure becomes negative. But this is a property of the many-body system's thermodynamics, not a vacuum that "pulls" particles more strongly than empty space.